



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application No: 09/826,458
Applicants: Xi-Cheng Zhang et al.
Filed: April 5, 2001
Title: TERAHERTZ TRANSCEIVERS AND METHODS FOR EMISSION
AND DETECTION OF TERAHERTZ PULSES USING SUCH
TRANSCIVERS
TC/A.U.: 2878
Examiner: Shun K. Lee
Confirmation No.: 6513
Docket No.: RPI-103US

DECLARATION

I, Xi-Cheng Zhang, hereby declare that:

1. I am a co-inventor of the above-captioned application.

1. I have a B.S. degree in physics from Peking University in Beijing, China, and an M.S. and Ph.D. in physics from Brown University.

2. I am currently employed as the J. Erik Johnsson '22 Professor of Science by Rensselaer Polytechnic Institute (RPI), and am a Professor in the Department of Physics, Applied Physics, and Astronomy and in the Department of Electrical, Computer & System Engineering.

3. The *Curriculum Vitae* attached to this Declaration (which is a print-out of information posted online on the THz Science and Technology page of the RPI website at <http://www.rpi.edu/~zhangxc/personnelhome.htm>) includes, among other things, a list of the granted patents of which I am a co-inventor and numerous journal publications in the field of terahertz (THz) science and technology of which I have been an author.

4. As a leading researcher in THz field, I keep abreast of the latest developments in THz science and technology, including reading journal articles, providing peer-review of articles for others before they are published, and continuing to lead research teams at RPI working at the forefront of THz technology. Thus, at

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the time the above-captioned invention was made, I was very familiar with the body of known THz technology at that time.

5. In the course of development of the method and system that is claimed in the subject patent application, the other co-inventors and I worked for several months before discovering that chopping the THz pulse was an important feature that rendered the claimed system and method functional.

6. Although it was well-known in the art to chop the pump beam or probe beam in a THz system, to the best of my knowledge, it was not known to chop the *THz pulse* at the time the invention was made, nor was I aware of any suggestion in the art to do this. During the development of our invention, we found that chopping the pump or probe beam generated feedback noise to the laser cavity that would either break the mode-locked laser or increase the laser noise, which was undesirable because of the extreme sensitivity of the measurement required for a THz transceiver. After considerable work and investigation, we found that chopping the THz pulse instead of the pump or probe beam avoided the problems inherent in chopping the pump or probe beam, and was a highly influential feature in making the invention operational. This has not been realized by others. Had it been known in the art or had there had been any teaching or suggestion in the art prior to the time the invention was made to chop the THz pulse, the co-inventors and I would have been aware of such teaching or suggestion, and it would not have taken us so long to develop this method and associated system.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the above-identified application or any patent issued thereon.

Dated: 6/27/03
Xi-Cheng Zhang

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Professional Experience:

02/02-present	Chair Professor	Capital Normal University of Beijing
02/02-present	Guest Professor	Shanghai Institute of Metallurgy, Chinese Academy of Sciences
10/01-present	Chair Professor	J. Erik Johsson'22 Distinguished Professor, RPI
03/98-present	Professor	Department of Electrical, Computer & System Engineering, RPI
08/97-present	Honorary Professor	Institute of Optics and Precision Mechanics, Chinese Academy of Sciences
05/97-present	Professor	Department of Physics, RPI
01/92-05/97	Associate Professor	Department of Physics, RPI
08/87-12/91	Research Scientist	Department of Electrical Engineering, Columbia University
05/85-07/87	Research Physicist	Amoco Research Center
05/84-04/85	Guest Scientist	Massachusetts Institute of Technology

Adjunct Positions:

08/1997	Honorary Professor	Institute of Optics and Precision Mechanics, Chinese Academy of Sciences
05/1996	Adjunct Professor	Xiamen University
01/1994	Adjunct Professor	Institute of Physics, Chinese Academy of Sciences
07/1993	Guest Professor	Institute of Semiconductors, Chinese Academy of Sciences
08/1991	Advisory Professor	Shanghai University of Science and Technology

Education:

1986	Ph.D. (Physics)	Brown University, RI.
1983	M.Sc. (Physics)	Brown University, RI.
1982	B.S. (Physics)	Peking University, Beijing, China

Research Interest:

Ultrafast optics, electronics and optoelectronics; Nonlinear photonics; Semiconductor characterization.

Professional Activities:

2002 Committee member, XIII Topical Meeting of Ultrafast Phenomena, Vancouver, Canada

2002 Session chair, Pulsed THz-Beam Application, Conference of Laser and Electro-Optics (CLEO), Long Beach, CA

Committee member, Ultrafast Optics, Optoelectronics, and Applications, Conference of Laser and Electro-Optics (CLEO), Long Beach, CA 2002 Panelist for the National Science & Engineering Graduate Fellowship Program, American Society for Engineering Education

2002 Guest Professor, Capital Normal University of Beijing

2002 Panelist, National Science Foundation Graduate Research Fellowship Program Review

2002 Member, CLEO Program Subcommittee on Ultrafast Optics and Electronics
Chairman of Round Table Discussion, Symposium on Terahertz Sciences and Technology,

2001 National Chiao Tung University

2001 Program Committee Member, SPIE 4591, Electronics and Structures for MEMS II
Advisor, the THz-BRIDGE International Advisory Board, European THz Bridge Program,
the European Union Commission

2001 Guest Professor, Shanghai Institute of Micro-System and Information Technology, Chinese Academy of Sciences

2001 Session Chair, Terahertz Physics and Techniques, LEOS Annual Meeting

2001 Session Chair, Frequency Conversion, LEOS Annual Meeting

2001 Honorable Conference Chair, 1st International Conference on Terahertz Sensing and Imaging for Biomedical Application

2001 Member, Nonlinear Optics Conference

2001 Member, Ultrafast Phenomena

2000 Member, CLEO, Program Subcommittee on Ultrafast Optics and Electronics

2000 Session chair, Terahertz Physics and Applications, Ultrafast Electronics and Optics

2000 Session chair, Terahertz Optoelectronics I, LEOS Annual Meeting

1999 Chair of Physics Panel, National Defense Science and Engineering Graduate Fellow Program; Board of Editorial Committee

1999 Board of Editorial Committee, Laser Society of Japan

1999 Co-Chair, Conference on THz Spectroscopy and Application, SPIE

1998 Chair, Ultrafast Optics & Electronics, LEOS Annual Meeting

1995-1998 Chair, the Committee on Ultrafast Optics & Electronics, IEEE/LEOS

1997 Chair, Ultrafast Optics & Electronics, LEOS Annual Meeting

1996 Guest Editor, JSTQE on Ultrafast Electronics, Photonics and Optoelectronics
1995 Member of the Board of Governors, IEEE/LEOS
1993 Co-Chair, Conference on Ultrafast Laser and Technology, SPIE
1993 Member of the Committee on IEEE/LEOS Summer Topical Meeting
1993- Member of Physics Panel, National Defense Science and Engineering Graduate present Fellow Program
1993- present Guest editor for WuLi (Chinese Physics Journal)
1992- 1995 Member of the Committee on Ultrafast Optics & Electronics, IEEE/LEOS

Professional Affiliations:

Since 1992 Member of the Photonics Society of Chinese-American
Since 1991 Senior Member of the Institute of Electrical and Electronics Engineers
Since 1991 Senior Member of the Laser and Electro-Optics Society
Since 1988 Member of the International Society for Optical Engineering
Since 1988 Member of the Optical Society of America
Since 1991 Member of the American Physical Society

Honors and Awards:

2002 K.C. Wong Fellow, K.C. Wong Foundation (Hong Kong)
2001 J. Erik Jonsson Distinguished Professor, R.P.I.
2001 Fellow, the Optical Society of America
2001 Fellow, the Institute of Electrical and Electronics Engineers
2001 Outstanding Scientist Award, Natural National Science Foundation of China
2001 Outstanding Overseas Chinese Scholar, the Chinese Academy of Sciences
2000-04 Assessor of Overseas Exports of the Chinese Academy of Sciences
1999-00 Distinguished Lecturer, IEEE/LEOS
1998-99 Distinguished Lecturer, IEEE/LEOS
1996 Early Career Award, Rensselaer Polytechnic Institute
1995 CAREER Award (previous NSF-NYI), National Science Foundation
1995 K.C. Wong Prize, K.C. Wong Foundation (Hong Kong)
1995 Cottrell Scholar Award, Research Corporation
1993-94 AFOSR-SRPF Fellow, Hanscom Air Force Base
1992 Research Initiation Award, National Science Foundation
1991 Outstanding Young Scientist, Chinese Academy of Sciences
1981 CUSPEA, Brown University

1980 National Outstanding Student Award, Peking University

Professional Affiliations:

Since 1992 Member of the Photonics Society of Chinese-American
Since 1991 Senior Member of the Institute of Electrical and Electronics Engineers
Since 1991 Senior Member of the Laser and Electro-Optics Society
Since 1988 Member of the International Society for Optical Engineering
Since 1988 Member of the Optical Society of America
Since 1991 Member of the American Physical Society

Seminars, Colloquium, and Publications:

Featured in more than 20 magazines (including Wall Street Journal, US News & World Reports, American Scientists, etc); published 7 books and book chapters and more than 146 refereed journal papers.

Presentations:

Delivered more than 200 invited talks (89 invited, plenary, and key plenary conference presentations, 62 colloquium, and 65 seminars), and more than 100 contributed conference presentations (since 1990).

Patents and Disclosures:

US Patent No. 6,057,928, "Free-Space, Time-Domain Method for Measuring Thin Film Dielectric Properties," M. Li, X.-C. Zhang, and G.C. Cho, May 2, (2000).

US Patent No. 6,111,416, "Electro-Optical and Magneto-Optical Sensing Apparatus and Method for Characterizing Free-Space Electromagnetic Radiation," X.-C. Zhang, L. Libelo, Q. Wu, Jennifer Riordan, and Fengguo Sun, Patent Corporation Treaty, international patent (Japan, Canada, European countries), August 27, (2000).

US Patent No. 5,952,818, "Electro-Optic Sensing Apparatus and Method for Characterizing Free-Space Electromagnetic Radiation," X.-C. Zhang, L. Libelo, and Q. Wu, Sept. 14 (1999).

Continuation-in-part US patent pending, Serial No.:08/920,561, "Electro-Optical and Magneto-Optical Sensing Apparatus and Method for Characterizing Free-Space Electromagnetic Radiation," X.-C. Zhang, Jennifer Riordan, and Fengguo Sun, filed on August 29, (1997).

US Patent No. 5,420,595, "Microwave Radiation Source," X.-C. Zhang and D.H. Auston, MAY 30 (1995).

Books and Book Chapters:

1. L.-C. Zhao and X.-C. Zhang, Advanced Semiconductor Physics, University Textbook (Academy Sinica, China), HauDong Normal Univ. Publisher, ISBN 7-5617-0707-X (1992).
2. X.-C. Zhang, "Generation and Detection of THz EM Pulse from Dielectrics with Femtosecond Optics," a chapter in Ultra Fast Phenomena, CCAST-WL Series 38, Ed. by K. Shum, Y.J. Ding and X.-C. Zhang, pp89-115, Gordon and Breach Scientific Publishers, (1994)
3. X.-C. Zhang, "Generation and Detection of Terahertz Electromagnetic Pulsed Radiation from Semiconductor Crystals with Femtosecond Optics," a chapter in Compound Optoelectronic Materials and Devices, ISBN 0-646-21807-7, 69, (1995).
4. X.-C. Zhang and Y. Jin, "THz Electromagnetic Radiation from Dielectrics," Chapter 3 in Perspectives in Optoelectronics, Ed. by Jha, pp81-138, World Scientific (1995).
5. Zhiping Jiang and X.-C. Zhang, "Free-Space Electro-Optic Technologies", THz Sensing and Imaging Technology, Springer-Verlag, (2001).
6. Qin Chen and X.-C. Zhang, "Electro-Optic THz Imaging," Ultrafast Laser: Technology and Applications, Ed. By Fermann, Galvanauskas, Sucha, Marcel Dekker, Inc. (2001).

Refereed Journal Papers:

1. X.-C. Zhang, M. Gal and A.V. Nurmikko, "Free-Exciton Confinement by Layer Stacking Faults in GaSe: Evidence from Time-Resolved Spectroscopy," Phys. Rev. B 30, 6214 (1984).
2. X.-C. Zhang, Y. Hefetz and A.V. Nurmikko, "Kinetics of Free and Bound Excitons in Semiconductors," Ultrafast Phenomena IV, Springer Series in Chemical Physics, 38, 176 (1984).
3. X.-C. Zhang, S.K. Chang, A.V. Nurmikko, L.A. Koloziejski, R.L. Gunshor and S. Datta, "Excitonic Recombination at the CdTe/(Cd,Mn)Te Heterointerface," J. Vac. Sci. Technol. B 3, 1300 (1985).
4. X.-C. Zhang, S.K. Chang, A.V. Nurmikko, L.A. Koloziejski, R.L. Gunshor and S. Datta, "Interface Localization of Excitons in CdTe/CdMnTe Multiquantum Wells," Phys. Rev. B 31, 4056 (1985).
5. X.-C. Zhang, S.K. Chang, A.V. Nurmikko, L.A. Koloziejski, R.L. Gunshor and S. Datta, "Time-Resolved Exciton Recombination in CdTe/Cd_{1-x}Mn_xTe Multiquantum Wells," Appl. Phys. Lett. 47, 59 (1985).
6. X.-C. Zhang, S.K. Chang, A.V. Nurmikko, L.A. Koloziejski, R.L. Gunshor, S. Datta and D. Heiman, "Influence of High Magnetic Fields on Exciton Luminescence of Cd_{1-x}Mn_xTe Multiquantum Wells," Solid State Commun. 56, 255 (1985).
7. A.V. Nurmikko, X.-C. Zhang, S.K. Chang, L.A. Koloziejski, R.L. Gunshor and S. Datta, "Excitons in CdMnTe Multiquantum Wells," Journal of Luminescence 34, 89 (1985).
8. L.A. Koloziejski, R.L. Gunshor, N. Otsuka, X.-C. Zhang, S.K. Chang and A.V. Nurmikko, "(100) Superlattices of CdTe-Cd_{0.76}Mn_{0.24}Te on (100) GaAs," Appl. Phys. Lett. 47, 882 (1985).
9. Y. Hefetz, X.-C. Zhang and A.V. Nurmikko, "Observation of Exciton-Exciton Scattering in Cu₂O by Time-Resolved Photomodulation Spectroscopy," Phys. Rev. B 31, 5371 (1985).
10. X.-C. Zhang, Y. Hefetz, S.K. Chang, J. Nakahara and A.V. Nurmikko, "Excitons and Their Kinetics in CdTe/(CdMn)Te and ZnSe/(Zn,Mn)Se Quantum Wells," Surf. Sci. 174, 292 (1986).
11. X.-C. Zhang and R.K. Jain, "Measurement of On-Chip Waveforms and Pulse Propagation in Digital GaAs Integrated Circuits by Picosecond Electro-Optic Sampling," Electronics Letters 22, 264 (1986).

12. X.-C. Zhang, R.K. Jain, M.G. Ressl and T.J. Pier, "Precise Measurement of Signal Propagation Characteristics in GaAs Integrated Circuits by Picosecond Electro-Optic Sampling," *Ultrafast Phenomena V*, Springer Series in Chemical Physics, 46, 107 (1986).
13. X.-C. Zhang, R.K. Jain and R. Hickling, "Electro-Optic Sampling Analysis of Timing Patterns at Critical Internal Nodes in Gigabit GaAs Multiplexers / Demultiplexers," *Picosecond Electronics and Optoelectronics II*, Springer Series in Electronics and Photonics 24, 29 (1987).
14. X.-C. Zhang, B.B. Hu, J.T. Darrow and D.H. Auston, "Generation of Femtosecond Electromagnetic Pulses from Semiconductor Surfaces," *Appl. Phys. Lett.* 56, 1011 (1990).
15. X.-C. Zhang, J.T. Darrow, B.B. Hu, D.H. Auston, M.T. Schmidt, P. Tham and E.S. Yang, "Optically Induced Electromagnetic Radiation from Semiconductor Surfaces," *Appl. Phys. Lett.* 56, 2228 (1990).
16. J.T. Darrow, B.B. Hu, X.-C. Zhang and D.H. Auston, "Subpicosecond Electromagnetic Pulses from Large Aperture Photoconducting Antennas," *Opt. Lett.* 15, 323 (1990).
17. B.B. Hu, X.-C. Zhang, D.H. Auston and P.R. Smith, "Free Space Radiation from Electro-Optic Crystal," *Appl. Phys. Lett.* 56, 506 (1990).
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19. C. Shu, B.B. Hu, X.-C. Zhang, P. Mei and E.S. Yang, "Picosecond Photoconductive Response of Polycrystalline Silicon Thin Films," *Appl. Phys. Lett.* 57, 64 (1990).
20. X.-C. Zhang, B.B. Hu, S.H. Xin and D.H. Auston, "Optically Induced Femtosecond Electromagnetic Pulses from GaSb/AlSb Strained Layer Superlattices," *Appl. Phys. Lett.* 57, 753, (1990).
21. B.B. Hu, X.-C. Zhang and D.H. Auston, "Temperature Dependence of Optically Induced Femtosecond Electromagnetic Radiation from Semiconductor Surfaces," *Appl. Phys. Lett.* 57, 2629 (1990).
22. C. Shu, X.-C. Zhang, E.S. Yang and D.H. Auston, "Generation and Propagation of Optoelectronic Signals in Coplanar Waveguides," *Appl. Phys. Lett.* 57, 2897 (1990).

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23. X.-C. Zhang, J.T. Darrow, B.B. Hu, S.H. Xin and D.H. Auston, "Optically Induced Electromagnetic Radiation from Semiconductor Surfaces," *Ultrafast Phenomena VII*, Springer Series in Chemical Physics, 53, 198 (1990).
24. D.H. Auston and X.-C. Zhang, "Large Aperture Photoconducting Antennas," *Picosecond Electronics and Optoelectronics VI*, Springer Series in Electronics and Photonics, 1 (1991).
25. J.T. Darrow, X.-C. Zhang and D.H. Auston, "Power Scaling of Large-Aperture Photoconducting Antennas," *Appl. Phys. Lett.* 58, 25 (1991).
26. N. Froberg, M. Mack, B.B. Hu, X.-C. Zhang and D.H. Auston, "500 GHz Electrically-Steerable Photoconducting Antenna Array," *Appl. Phys. Lett.* 58, 446 (1991).
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28. C. Shu, X. Wu, E.S. Yang, X.-C. Zhang and D.H. Auston, "Propagation Characteristics of Picosecond Electrical Pulses on a Periodically Loaded Coplanar Waveguide," *IEEE Trans. Microwave Theory Tech. MTT-39*, 930 (1991).
29. X.-C. Zhang and D.H. Auston, "Generation of Steerable Submillimeter-Waves from Semiconductor Surfaces by Spatial Light Modulators," *Appl. Phys. Lett.* 59, 768 (1991).
30. B.B. Hu, X.-C. Zhang and D.H. Auston, "Terahertz Radiation Induced by Subbandgap Femtosecond Optical Excitation of GaAs," *Phys. Rev. Lett.* 67, 2709 (1991).
31. P.M. Ferm, C. Knapp, C.-J. Wu, J.T. Yardley, B.B. Hu, X.-C. Zhang and D.H. Auston,

"Ultrafast Electro-Optic Effect in Poled Polymer Films," *Appl. Phys. Lett.* 59, 2651 (1991).

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33. L. Xu, X.-C. Zhang, D.H. Auston and B. Jalali, "Terahertz Radiation from Large Aperture Silicon p-i-n Diodes," *Appl. Phys. Lett.* 59, 3357 (1991).

34. L. Xu, X.-C. Zhang, D.H. Auston and W.I. Wang, "Internal Piezoelectric Field in Strained Layer GaInSb/InAs Superlattices Probed by Optically Induced Microwave Radiation," *Appl. Phys. Lett.* 59, 3562 (1991).

35. J.T. Darrow, X.-C. Zhang, D.H. Auston and J.D. Morse, "Saturation Properties of Large-Aperture Photoconductor Antennas," *IEEE J. Quantum Electron.*, 28, 1607, (1992).

36. L. Xu, X.-C. Zhang and D.H. Auston, " TERAHERTZ BEAM GENERATION BY FEMTOSECOND OPTICAL PULSES IN ELECTROOPTIC MATERIALS," *Appl. Phys. Lett.* 61, 1784 (1992).

37. Froberg, B.B. Hu, X.-C. Zhang and D.H. Auston, "Terahertz Radiation from a Photoconducting Antenna Array," *IEEE J. Quantum Electron.*, 28, 2291 (1992).

38. S. Wu, X.-C. Zhang and R.L. Fork, "Direct Experimental Observation of Interactive Third and Fifth Order Nonlinearities in a Time and Space Resolved Four-Wave Mixing Experiment," *Appl. Phys. Lett.* 61, 919 (1992).

39. X.-C. Zhang, Y. Jin, B.B. Hu, X. Li and D.H. Auston, "Optoelectronic Study of Piezoelectric field in Strained-Layer Superlattices," *Superlattices and Microstructures*, 12, 487 (1992).

40. X.-C. Zhang, X.F. Ma, Y. Jin, T.-M. Lu, E. P. Boden, P. D. Phelps, K. R. Stewart and C. P. Yakymyshyn, "THz Optical Rectification from Highly Nonlinear Organic Crystals," *Appl. Phys. Lett.* 61, 3080 (1992).

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42. X.-C. Zhang and D.H. Auston, "Optically Induced THz Electromagnetic Radiation from Planar Photoconductive Antennas," *J. Electromagnetic Waves and Applications*, 6, 85 (1992).

43. X.-C. Zhang and D.H. Auston, "Optoelectronic Measurement of Semiconductor Surfaces and Interfaces with Femtosecond Optics," *J. Appl. Phys.* 71, 326 (1992).

44. X.-C. Zhang, Y. Jin, K. Yang and L.J. Schowalter, "Resonance Nonlinear Susceptibility near the Bandgap of GaAs," *Phys. Rev. Lett.* 69, 2303 (1992).

45. P.M. Ferm, C. Knapp, C.-J. Wu, J.T. Yardley, B.B. Hu, X.-C. Zhang and D.H. Auston, "Frequency Response of Electro-Optic Polymer," *Nonlinear Optics*, 5, 361 (1993).

46. X.-C. Zhang and Y. Jin, "Optically Induced THz Electromagnetic Radiation and Its Applications," *WuLi (Physics)*, 3, 136 (1993).

47. X.-C. Zhang, Y. Jin, T.D. Hewitt, T. Sangsiri, L.E. Kingsley and M. Weiner, "Magnetic Switching of THz Beams," *Appl. Phys. Lett.* 62, 2003, (1993).

48. X.-C. Zhang, Y. Jin, L.E. Kingsley and M. Weiner, "Influence of Electric and Magnetic Fields on THz Beams," *Appl. Phys. Lett.* 62, 2477 (1993).

49. X.F. Ma and X.-C. Zhang, "Determination of Ratios Between Nonlinear Optical Coefficients by Using Subpicosecond Optical Rectification," *JOSA B*, 10, 1175 (1993).

50. X.-C. Zhang, "New Terahertz Sources and Applications," *IEEE/LEOS News Letter*, 7-4, 14 (1993).

51. X.-C. Zhang, Y. Jin, T.D. Hewitt, T. Sangsiri, L.E. Kingsley and M. Weiner, "Terahertz Radiation from Electro-Optic Crystals," *Ultra-Wideband, short-Pulse Electromagnetics*, Ed. by Bertoni, Carin and Felsen, Plenum Press, 21 (1993).

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(1993).

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CSCI
64. X.-C. Zhang and Y. Jin, "Generation of THz Radiation from Semiconductors," *Ultra-Wideband, Short-Pulse Electromagnetics II*, Ed. by Carin, Plenum Press, 17 (1995).
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